Using C-band Dual-Polarization Radar Signatures to Improve Convective Wind Forecasting at Cape Canaveral Air Force Station and NASA Kennedy Space Center

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The USAF's 45th Weather Squadron (45WS)

- Organization responsible for issuing warnings for hazardous weather events, including convective wind events, at CCAFS/KSC

- <u>Warning Thresholds</u>:
  1) Peak wind gust ≥ 35 knots
  2) Peak wind gust ≥ 50 knots
- <u>Desired lead times</u>:
  – 30 minutes for Threshold-1
  – 60 minutes for Threshold-2

Sources: Roeder et al. (2009, 2014)

- <u>Purpose</u>: identify C-band radar signatures to:
  1) Increase lead times and decrease false alarm ratios (FARs) for 45WS convective wind warnings
  2) Differentiate Threshold-1, Threshold-2, & null events
- <u>Motivation</u>:
  – Personnel Safety
  – Costs (facilities, space launches, payloads, etc.)
  – Higher FAR than desired
  – Lead times often not met

Wet Downbursts and Radar

- Some wet downburst ingredients (Srivastava 1987, Meischner et al. 1991):
  - Significant precipitation ice
    - Intense storm updraft
    - Melting over shallow layer
    - Melting vs. evaporation latent heat
  - Hydrometeor loading

- Reflectivity (Z_h) Core (Wakimoto and Bringi 1988, Tuttle et al. 1989)
  - Precipitation core (peak Z_h) descends to surface later in storm's lifetime
  - Time Z_h core reaches surface = time of downburst
  - Peak Z_h may serve as indicator of downburst strength (Loconto 2006)

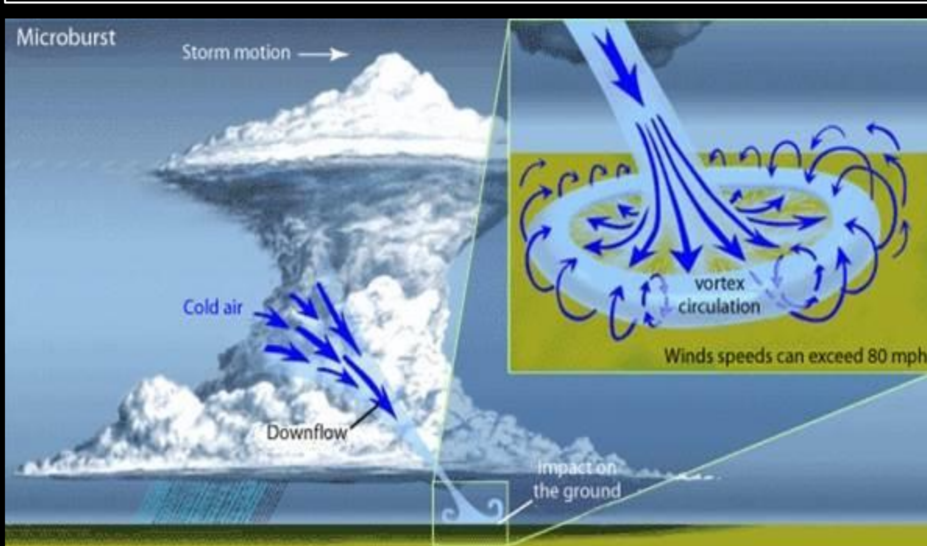


Image source: srh.noaa.gov

- Precipitation Ice Properties:
  - $Z_h \geq 29 – 33$ dBZ (Deierling et al. 2008)
    - 30 dBZ used in this study
  - Differential reflectivity (Z_{dr}) ≈ 0 dB
    - Spherical shape, tumbling, and/or lower dielectric (Herzegh and Jameson 1992)
  - Z_{dr} increases as falling ice melts
    - Often 3+ dB below 0 °C level (White 2015)

Wet Downburst Dual-Pol Signatures

- "Z_{dr} Column" (Illingworth et al. 1987, Tuttle et al. 1989)
  - Region of positive Z_{dr} values extending above environmental 0 °C level
  - Lofting of liquid drops by storm's updraft
  - Lofted drops freeze – leads to near-0 dB Z_{dr}
    - Results in lowered correlation coefficient (ρ_{hv})

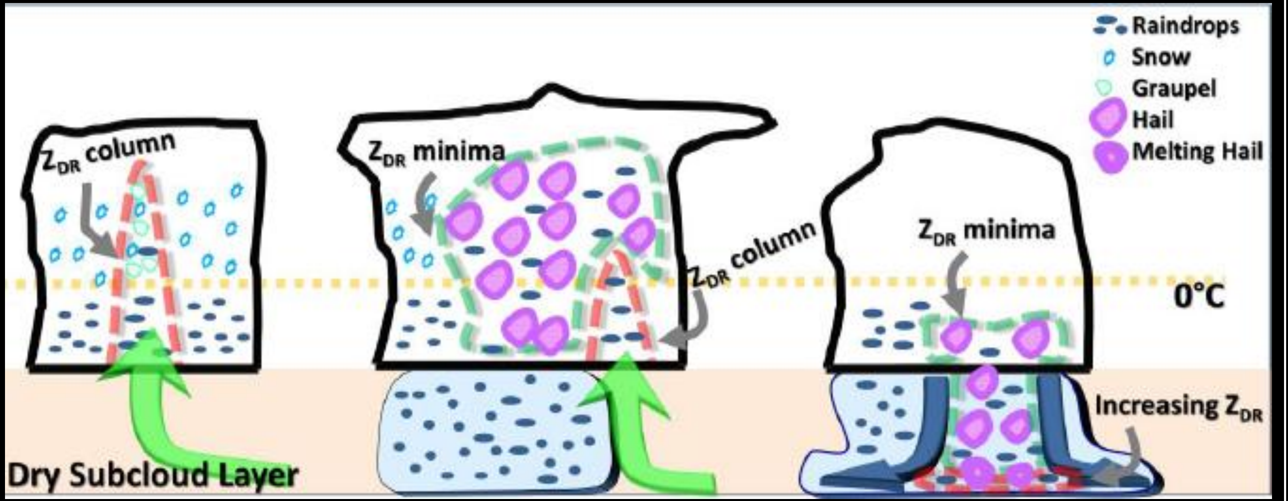


Figure source: Mahale et al. (2016), Fig. 13

- "Z_{dr} Hole" or "Z_{dr} Trough" (Wakimoto and Bringi 1988, Scharfenberg 2003)
  - Near-0 dB Z_{dr} region below 0 °C level
  - Descent of precipitation ice
- Sharp increase in Z_{dr} over shallow layer (Meischner et al. 1991)
  - Melting of small precipitation ice
  - Increased downward acceleration

Data and Methodology

Data

- C-band radar data from 45WS radar (45WS-WSR)
- KXMR sounding data
- Cape Weather Information Network Display System (Cape WINDS) tower data
- 10 “downburst days” from May – September 2015
  - Includes 14 threshold events and 4 null events

Methodology

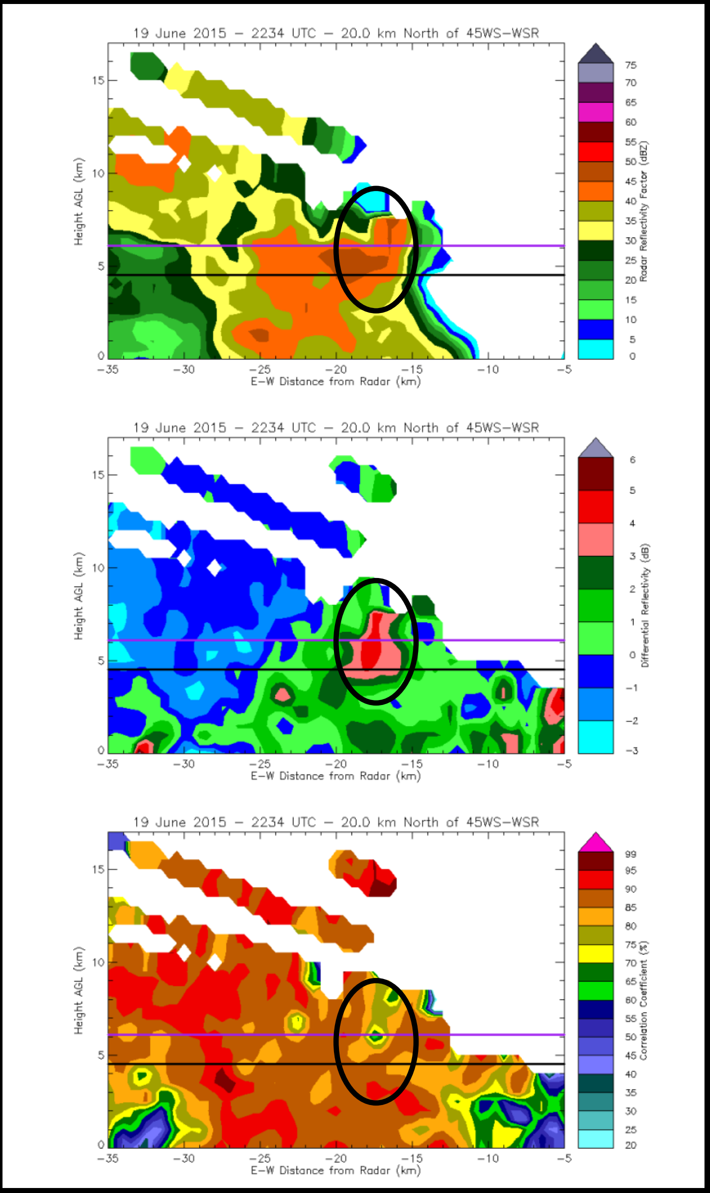
- Use IDL code to identify threshold-level wind gusts from Cape WINDS data
- Grid each radar volume scan using Py-ART; visualize using IDL
- Use Cape WINDS information and top-view radar images to identify downburst-producing storm cells
- Manually track cells back in time; use vertical cross sections of gridded radar data to analyze cells
- Use IDL codes to calculate environmental parameters
- Look for radar signatures common among threshold-level events

Results and Discussion

- Four main radar signatures identified so far:
  1) Peak height of 1 dB Z_{dr} contour above 0 °C level
  2) Peak height of co-located values of 30 dBZ Z_h and (approximately) 0 dB Z_{dr} above 0 °C level
  3) Peak Z_h value in storm cell
  4) Peak value of Z_{dr} in descending Z_h core 2.5 km below 0 °C level

- Much greater lead times offered in multicell events
  - Multiple updraft-downdraft cycles
- Other forcing mechanisms observed
  - E.g., sea breeze fronts, gust fronts, storm mergers
- Sources of future work

Signature #1 – 1 dB Z_{dr} Column Height

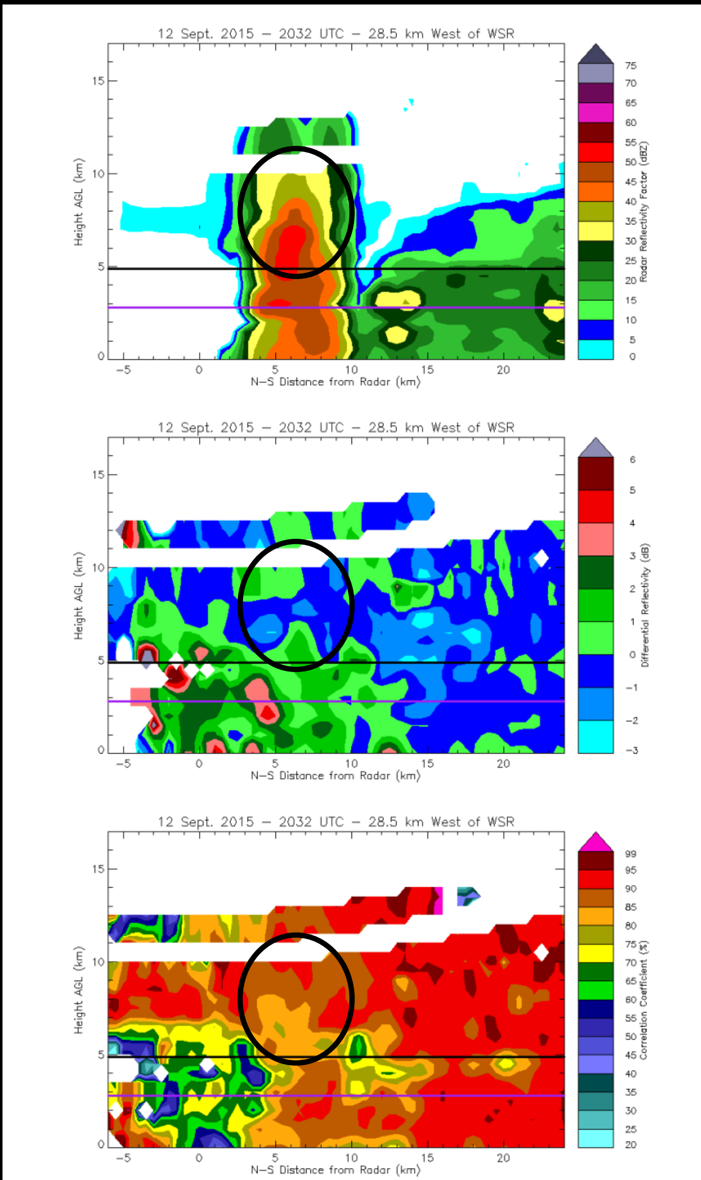


- Z_h (top), Z_{dr} (center), ρ_{hv} (bottom)
- East-West vertical cross sections
- Black line = 0 °C level
- Purple line = minimum θ_e level
- 35-knot downburst 48.5 min later

- Liquid hydrometeors lofted by updraft
- Freezing-melting, evaporation, loading all contribute to negative buoyancy

- Extended 1 km above 0 °C level in 85.71% (12 of 14) of threshold events and 100% (4 of 4) of null events
- Lead times: [11.50 min, 78.50 min]
  - Mean: 40.67 min; Median: 42.50 min

Signature #2 – Height of 30 dBZ Z_h and 0 dB Z_{dr}

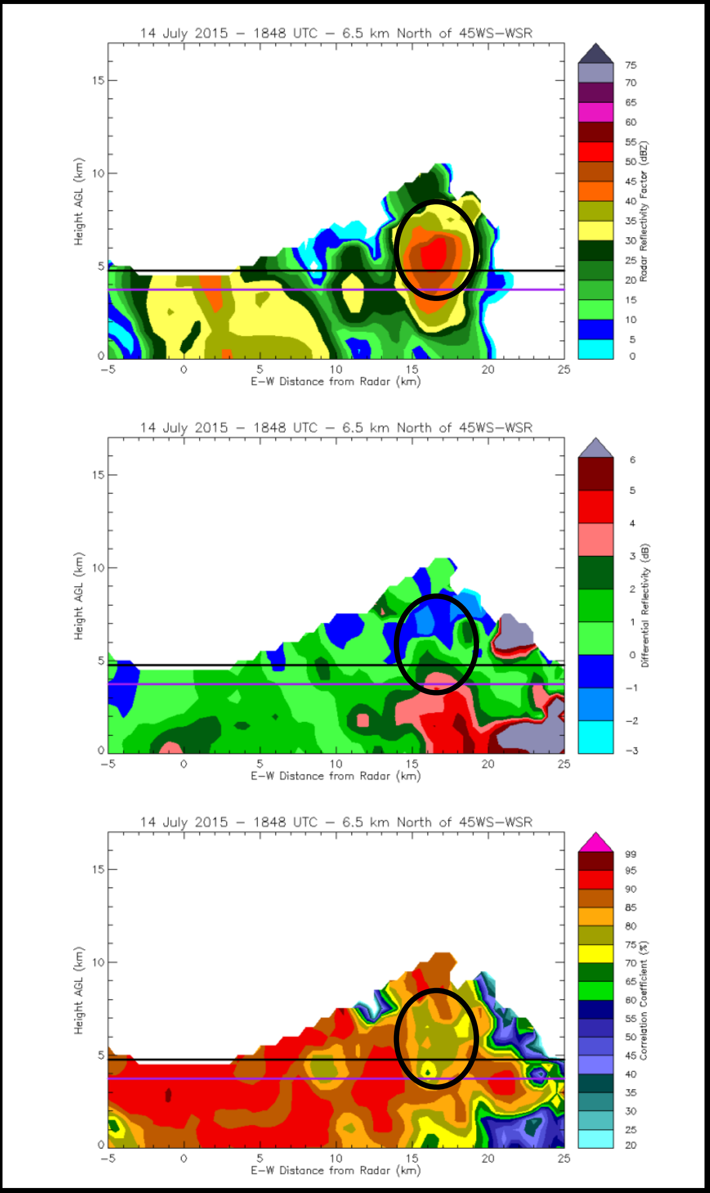


- Z_h (top), Z_{dr} (center), ρ_{hv} (bottom)
- North-South vertical cross sections
- 42-knot downburst 50.5 min later

- Presence of precipitation ice aloft
- Melting during descent below 0 °C level enhances negative buoyancy
  - Especially important to downbursts in humid environments (Srivastava 1987)

- Co-location extended 3 km above 0 °C level in 92.86% (13 of 14) of threshold events and 100% (4 of 4) of null events
- Lead times: [3.50 min, 78.50 min]
  - Mean: 40.88 min; Median: 35.50 min

Signature #3 – Peak Z_h Value

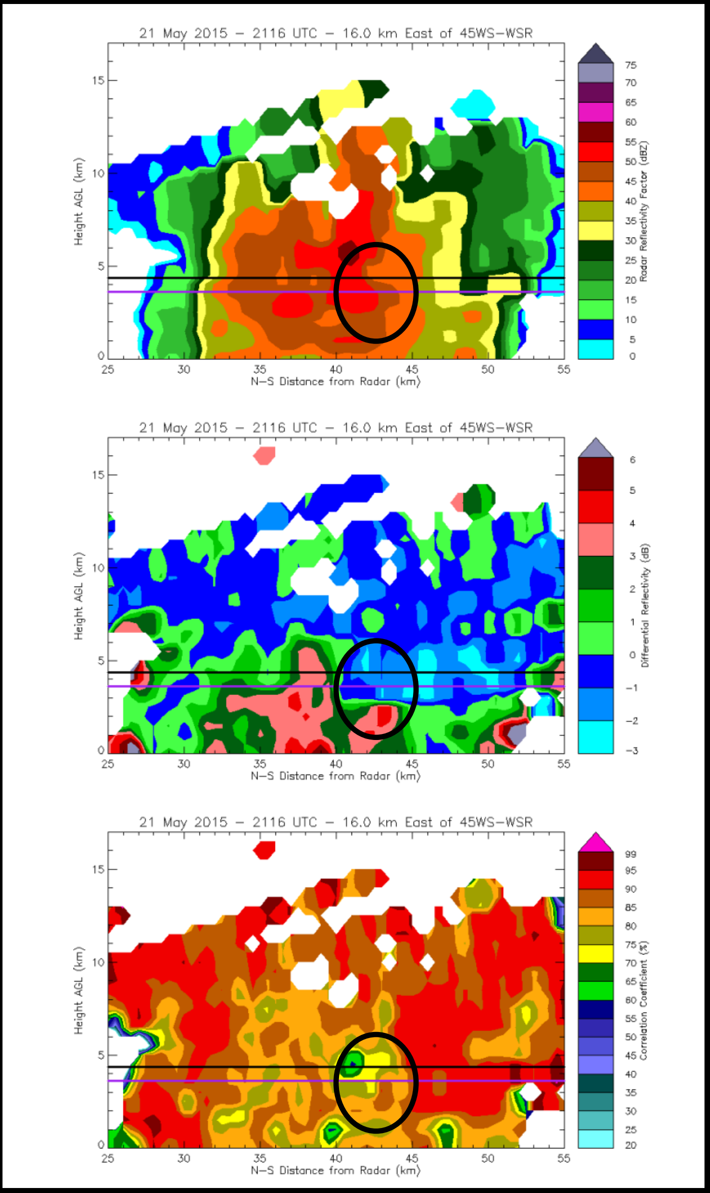


- Z_h (top), Z_{dr} (center), ρ_{hv} (bottom)
- East-West vertical cross sections
- 35-knot downburst 24.5 min later

- Presence of large-sized and/or large concentrations of hydrometeors
- Availability for loading and large degree of melting (ice) and evaporation (liquid), all of which enhance negative buoyancy

- Peak Z_h of at least 50 dBZ in 92.86% (13 of 14) of threshold events and 75% (3 of 4) of null events
- Lead times: [11.50 min, 78.50 min]
  - Mean: 45.88 min; Median: 48.50 min

Signature #4 – Vertical Z_{dr} Gradient



- Z_h (top), Z_{dr} (center), ρ_{hv} (bottom)
- North-South vertical cross sections
- 51-knot downburst 16.5 min later

- Large degree of precipitation ice melting over shallow layer below 0 °C level
- Strong contribution to negative buoyancy; increased downward acceleration in downburst

- Z_{dr} increased to 3 dB in 2.5 km below 0 °C level in 92.86% (13 of 14) of threshold events and 100% (4 of 4) of null events
- Lead times: [1.50 min, 78.50 min]
  - Mean: 40.42 min; Median: 41.50 min

Summary and Future Work

Summary

- Four radar signatures identified in threshold-level downburst events:
  1) 1 dB Z_{dr} column top at least 1 km above 0 °C level
  2) 30 dBZ Z_h co-located with 0 dB Z_{dr} extending 3+ km above 0 °C level
  3) Peak Z_h value of 50+ dBZ
  4) Increase in Z_{dr} in descending Z_h core to at least 3 dB within 2.5 km below 0 °C level
- Avg. lead time: 40 – 46 min

Future Work

- Include more events (both threshold and null)
  - Examine these four signatures
  - Explore other signatures, especially those unique to threshold-level events
- Examine environmental data in more detail
- Identify differences between 35-knot and 50-knot threshold events
- Algorithm development

Acknowledgements

- Work supported by *FUNDING INFO HERE*
- UAH Atmospheric Science (ATS) Department
  - Dr. Lawrence Carey
- USAF's 45th Weather Squadron
  - Mr. William Roeder
  - Mr. Todd McNamara
- USAF's 14th Weather Squadron
  - Mr. Jeffrey Zautner
- NASA Marshall Space Flight Center
  - Dr. Richard Blakeslee
- The first author would like to thank the following current and past members of UAH ATS / SWIRLL:
  - Sarah Stough, Retha Mecikalski, Alex Young, Chris Lisauckis, Bruno Medina, and Dustin Conrad

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